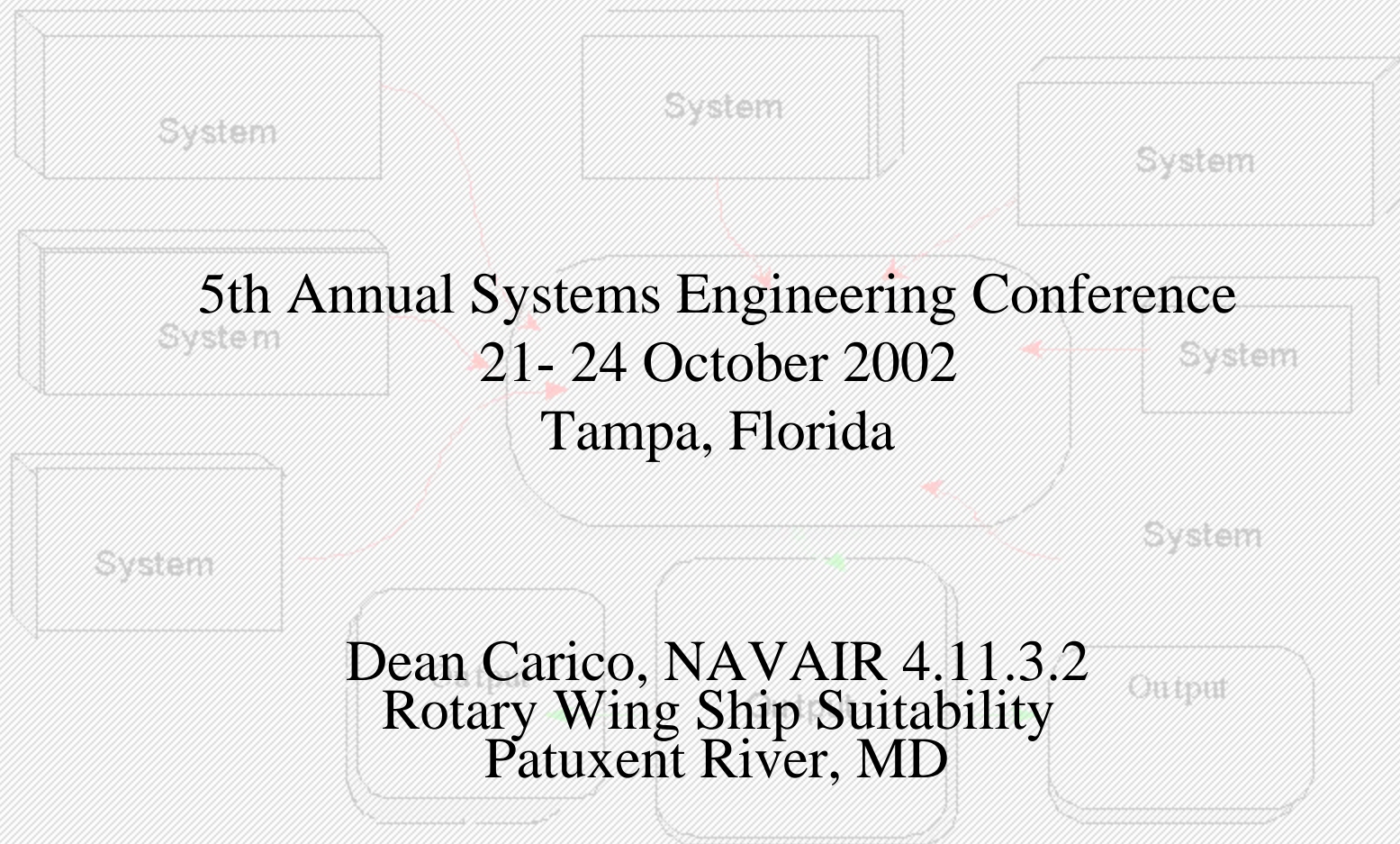


An Integrated Systems T&E Approach



Dean Carico, NAVAIR 4.11.3.2
 Rotary Wing Ship Suitability
 Patuxent River, MD

OUTLINE

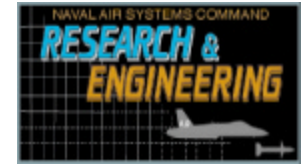
- T&E Overview
- Past T&E Focus
- Current T&E Emphasis
- T&E Complexity Changes
- T&E Engineering Options
- Integrated Systems T&E Approach
- Operational Scenario
- Summary

T&E Overview

- DoD Procurement Funds
- Current Cost of Rotorcraft Testing
 - Becoming more expensive
 - May uncover problems late in acquisition cycle
- Mission Rehearsal Training
 - OFT/WST Expensive
 - Far removed from battlefield site
- Acquisition & Mishap Investigations
 - Not integrated with flight testing



Past T&E Focus - Cost and Cycle Time



- **NAWCAD 4.11 BPR POC for T&E**
 - Jun 99 - Need to reduce T&E costs by 33% & cycle time by 50%
- **DR. JACQUES GANSLER - Into the 21st Century - A Strategy for Affordability**
 - JAN 1999 - ...We must further adapt the best world class business and technical practices to our needs, ... and reduce cycle times and ownership costs while simultaneously improving readiness
- **DR PAT SANDERS - ITEA JOURNAL**
 - JUN/JUL 1998 - The cost of testing can, and should be, reduced through the use of credible simulation

Current T&E Emphasis

- **Interoperability**
 - The ability of systems to provide services to and accept services from other systems
 - DoD 5000 series requires that all systems must be designed and tested to ensure interoperability
- **System-of-Systems (SoS)**
 - A system working with a group of other systems or sub-systems in a seamless environment

T&E Complexity Changes



- Wright Flyer – 1903
- Sikorsky R-4 Helicopter – 1942
- Sikorsky SH-60B LAMPS MK3 – 1983
- Bell Boeing V-22 – 1989
- Lockheed Martin JSF – 2000



T&E Engineering

- Focus
 - Avionics; Design; Engines and Power Trains
 - Flight Dynamics; Flight Controls
 - Performance; Structures and Loads
 - Ship Suitability
- Matrix Organization
 - Advantage: Technical Specialties
 - Disadvantage: “Rice Bowls” – Very difficult to get project approved that benefits everyone

T&E Options

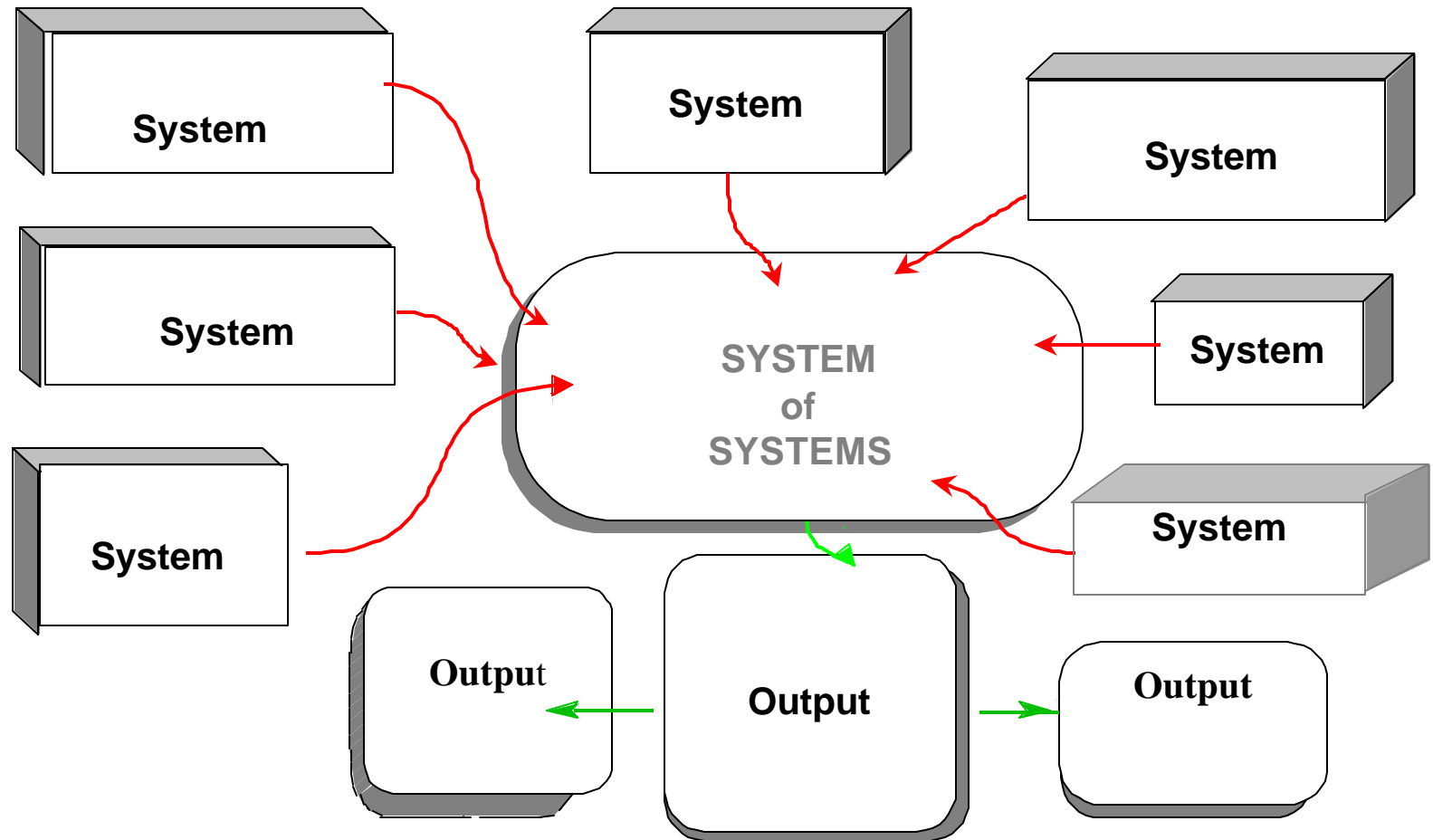
- Business as usual - Conventional T&E
 - Introduction of personal computer in the 1980's
 - Introduction of the WWW in the 1990's
 - Cost & Cycle Time Problems
- Combine Conventional T&E and Virtual T&E using related technology options
 - Develop and validate an analytic capability to support and enhance conventional T&E

DoD 5000.2-R Requirements

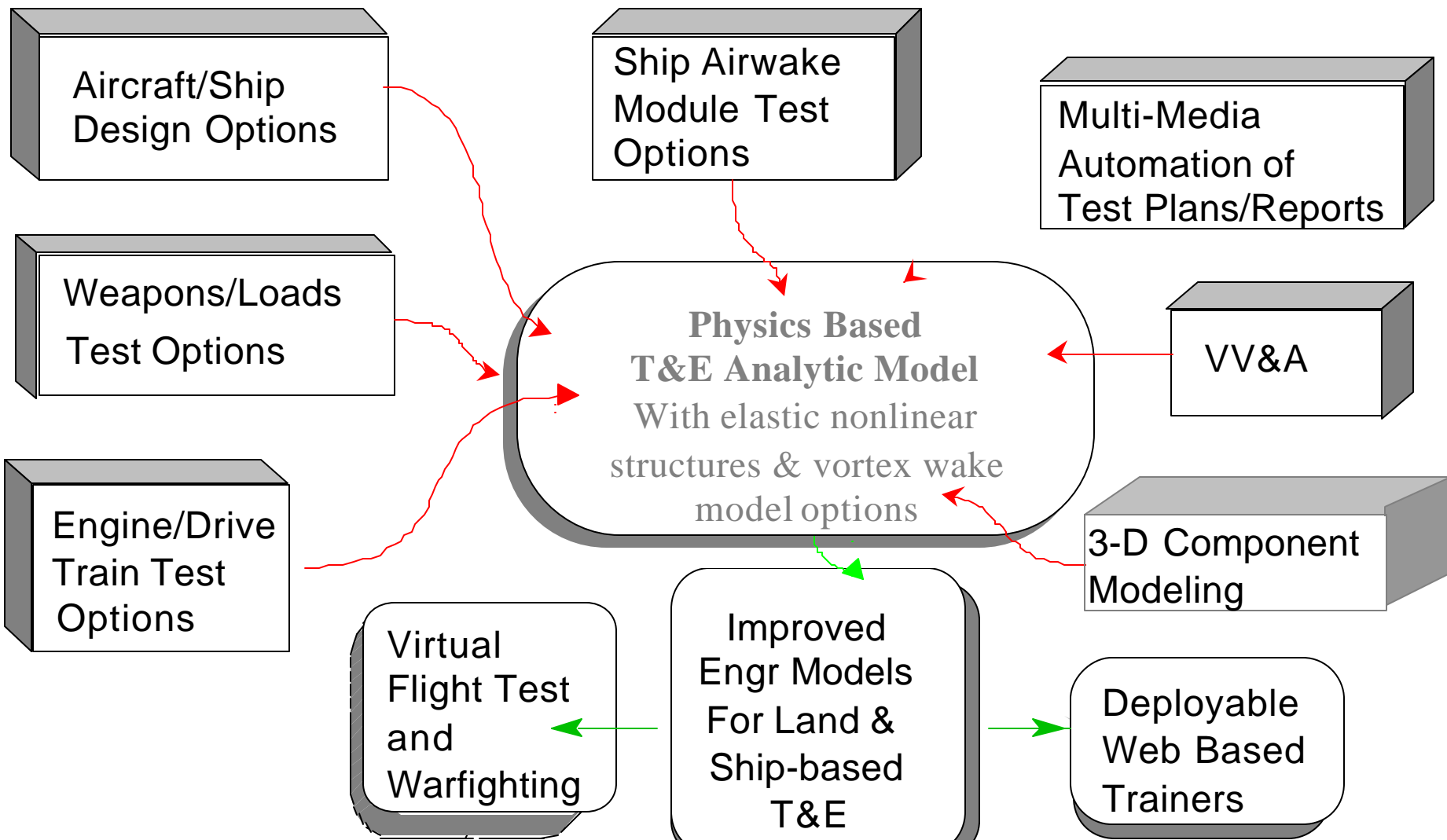
(5 Apr 2002)

- **C1.1 Modeling and Simulation**
- The PM shall identify and fund required M&S resources early in the acquisition life cycle, so M&S may be integrated with the T&E program
- The PM shall use test results to revise both the test program and test procedures
- Test results shall also be used to develop and improve models and simulations

System of Systems (SoS) Approach



SoS T&E Approach



Physics-based T&E Analytic Model (Flightlab)

The screenshot displays the Flightlab software interface, which is used for configuring a physics-based T&E (Test and Evaluation) analytic model. The interface is divided into two main sections: a hierarchical model tree on the left and a detailed parameter configuration panel on the right.

Model Tree (Left Panel):

- Rotorcraft Model
 - Solution Parameters
 - Environment
 - Main Rotor
 - Blade Element** (Selected)
 - Blade Structure
 - Articulated
 - Airloads
 - Induced Velocity
 - Peters/He Three State
 - Rotor Interference
 - Tail Rotor
 - Wing
 - Airframe
 - Fuselage
 - Empirical Fuselage Airloads
 - Aerodynamic Surfaces
 - Miscellaneous Airloads
 - Panel Method
 - Pilot Station
 - Sensor
 - Cargo Load
 - Landing Gear
 - External Body
 - Propulsion
 - Flight Control
 - User-defined subsystem

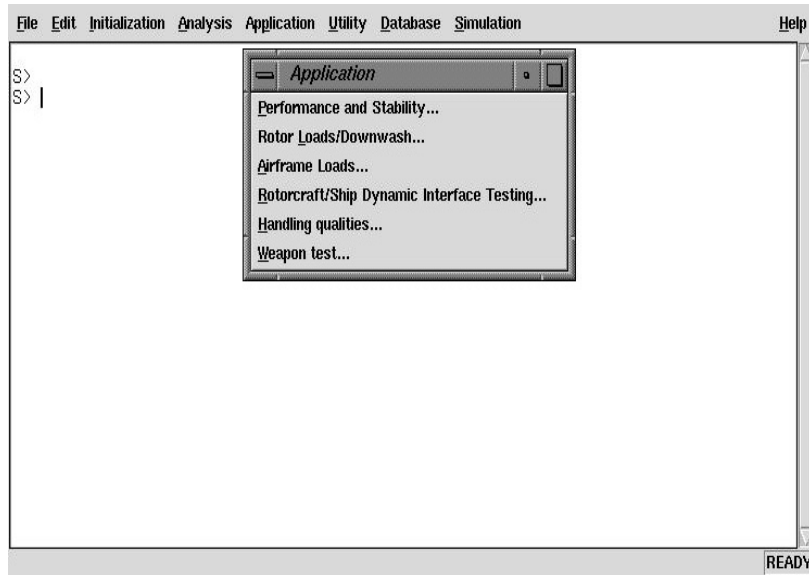
Blade Element Configuration (Right Panel):

The configuration panel for the selected **Blade Element** includes the following parameters:

- Rotor direction:** 0: Counterclockwise rotor
- Rotor hub location:** 29.0 0.0 26.0 ft
- Number of rotor blades:** 4
- Blade tip loss factor:** 0.97
- Hub orientation in Euler angles:** 0.0 177.0 0.0 deg
- Axis about which rotor shaft tilts:** 2
- Rotor nominal speed:** 27.0 rad/sec
- Rotor radius:** 27.0 ft
- Swashplate phase angle:** -10.0 deg

The bottom status bar shows the current node is **node11** and the rotor is **berotor**.

Analytic Flight Test Support Options



ID	Test Type	Test Conditions				Test Configuration			FCS Status 1/0	Others	Plot Options
		AS KCAS	Hp FT	OAT Deg C	Nr RPM	WT LBS	FSCG Inch	BLCG Inch			
■	Hover	0	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Critical Azimuth	20	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Low Speed	0	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Level Flight	40	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Climb	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Autorotation	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Coordinated Turn	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Lng Stat Stability	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Lat/Dir Stat Stab	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Maneuvering Stab	60	0	15	257.8	16269	360	0	1	Inputs...	Results...

Buttons at the bottom: Run, Reset, Stop..., Limits..., Recover Results, Close, Help...

Input data option: ◆ Compute data (nonlinear) ◇ Compute data (linear)

ID	Test Type	Test Conditions			Test Configuration			Plot Options
		AS KCAS	Hp FT	OAT Deg C	WT LBS	FSCG Inch	BLCG Inch	
■	Damping	0	0	15	16307.7	360	0	Results...
■	Quickness	0	0	15	16307.7	360	0	Results...
■	Bandwidth	0	0	15	16307.7	360	0	Results...
■	Bank Angle Oscillation	0	0	15	16307.7	360	0	Results...
■	Pitch/Roll Oscillation	0	0	15	16307.7	360	0	Results...
■	Lat-Dir Stability	50	0	15	16307.7	360	0	Results...
■	Yaw-due-Collective	0	0	15	16307.7	360	0	Results...
■	Torque Response	0	0	15	16307.7	360	0	Results...
■	Turn Coordination	50	0	15	16307.7	360	0	Results...

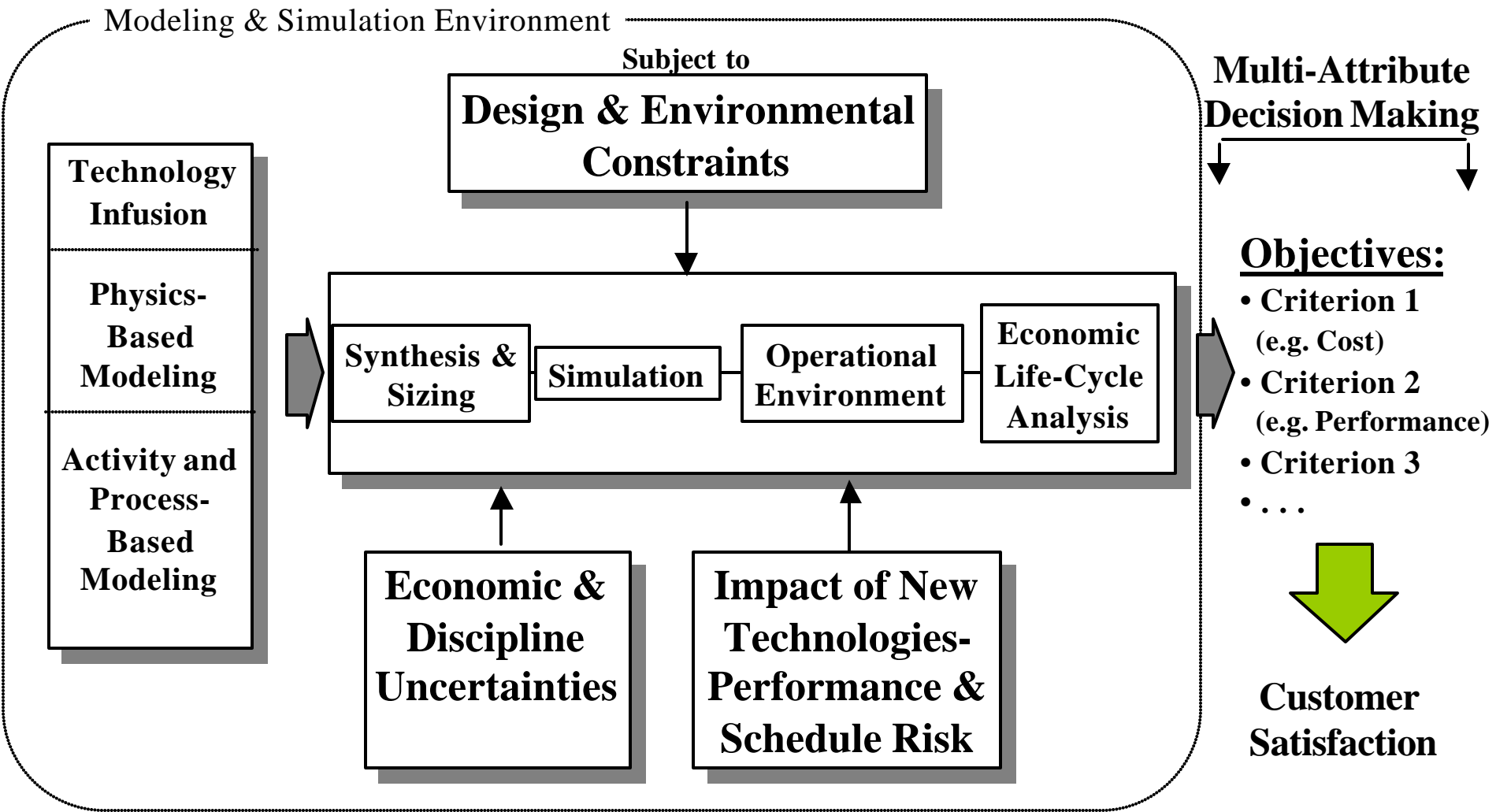
Buttons at the bottom: Run, Close, help...

Analysis option: ◇ Steady state... ◆ Trim... ◇ Maneuver...

Azimuth/time variation data	Azimuth/time and spanwise variation data
Rotor hub force (Fx) [lbs] Rotor hub force (Fy) [lbs] Rotor hub force (Fz) [lbs] Rotor hub moment (Mx) [ft-lbs] Rotor hub moment (My) [ft-lbs] Rotor hub moment (Mz) [ft-lbs] Tip-plane-path (coning) [deg] Tip-plane-path (lat tilt) [deg] Tip-plane-path (lng tilt) [deg]	Airload drag coefficients (cd) [nd] Airload lift coefficients (cl) [nd] Airload pitch moment coeff (cm) [nd] Airloads (drag) [lbs/ft] Airloads (lift) [lbs/ft] Airloads (pitch moment) [lbs] Angle of attack [deg] Blade cross section loads (Fx) [lbs] Blade cross section loads (Fy) [lbs] Blade cross section loads (Fz) [lbs]

Buttons at the bottom: ◆ Azimuth ◇ Harmonic... ◆ Azimuth... ◇ Radial... Run, Save..., Close, Plot, help...

Robust Design Simulation



Weapons & Loads Testing

- Weapons
 - Guns
 - Missiles & Rockets
 - Bombs
- Loads
 - Steady
 - Vibratory

AEDC Engine Modeling

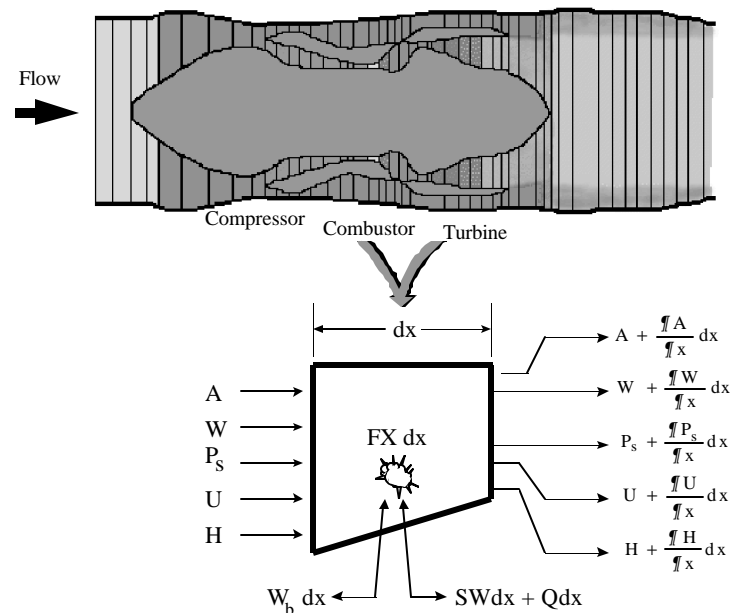
- The Aerodynamic Turbine Engine Code solves the 1-D Euler Equations with Turbomachinery Source Terms across elemental control volumes:

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} = \mathbf{G}$$

where:

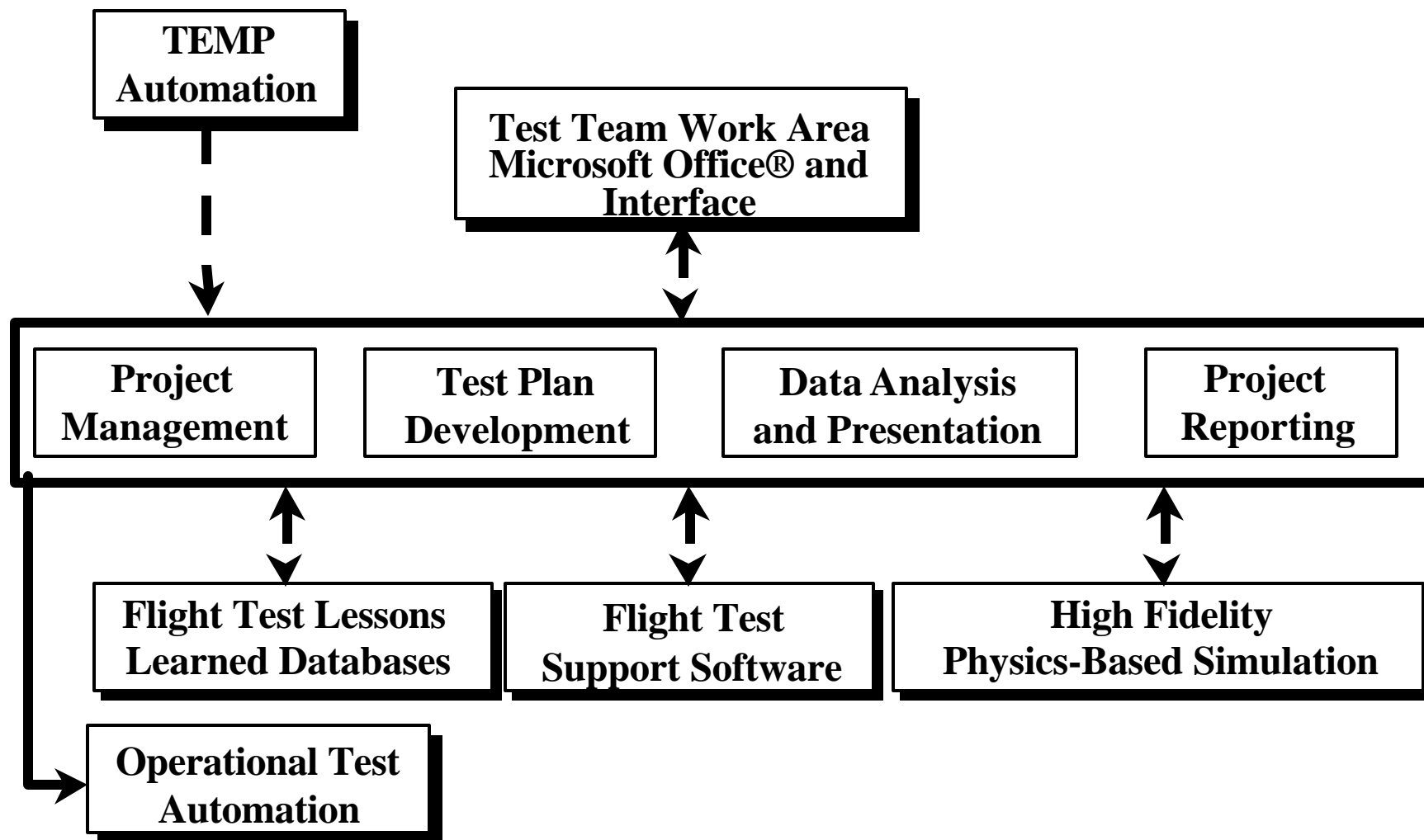
$$\mathbf{U} = \begin{bmatrix} A\mathbf{r} \\ \mathbf{r}Au \\ AE \end{bmatrix} \quad \mathbf{F} = \begin{bmatrix} \mathbf{r}Au \\ \mathbf{r}Au^2 + AP \\ u(AE + AP) \end{bmatrix} \quad \mathbf{G} = \begin{bmatrix} -W_{B_x} \\ F_x \\ Q_x + SW_x - H_{B_x} \end{bmatrix}$$

- Variable time-stepping routine using both explicit and implicit numerical solvers ensures efficient transient simulation with high fidelity dynamic simulation



Discretization of system
into elemental control volumes

Flight Test Automation

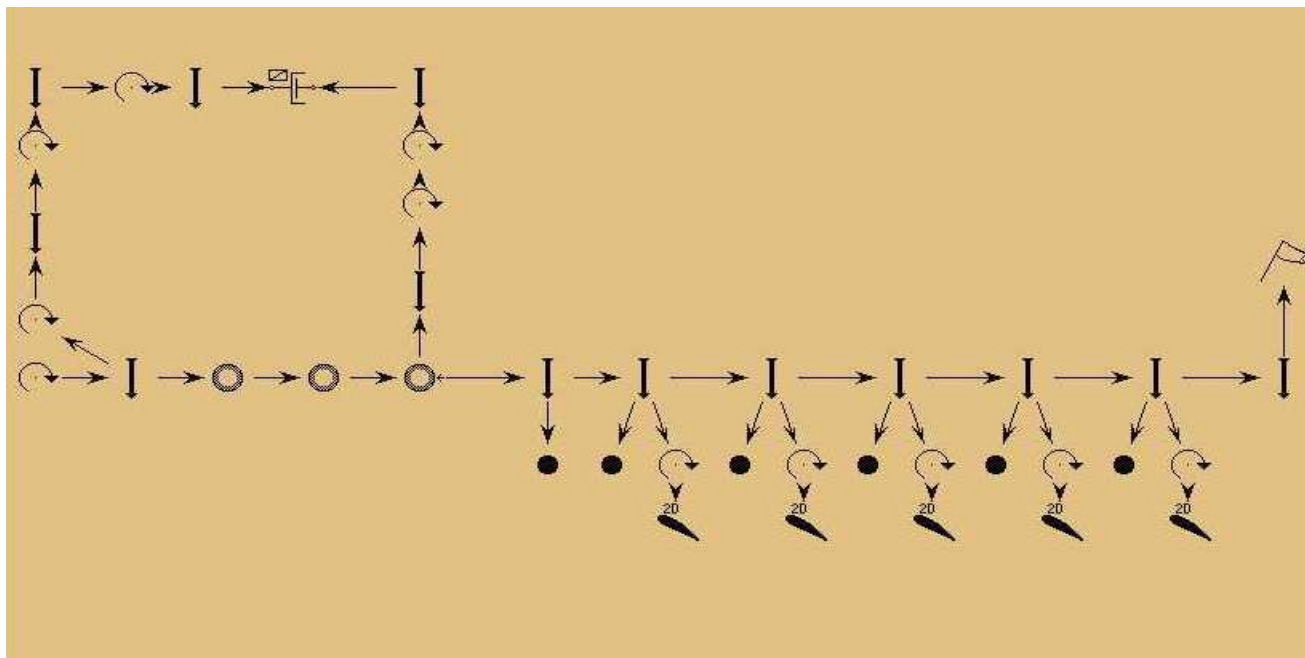


VV&A

- **Required:** Sanity check of model structure
- **Verification** - Was model programmed and/or implemented correctly?
- **Validation** - How close does model compare with real world data?
- **Accreditation** - Process of approving model for specific applications
- **Built-in V&V options**

3-D Component Modeling

- Flight Test Engineers work in a 3-D world
- Rotorcraft fly in 3-D world
- Model development & analysis in 2-D



Dynamic Interface (DI) Rotorcraft/Ship Operational Challenges

Shipboard Rotorcraft Operation Environment

- High & Turbulent Winds
- Possible Low Visibility Condition
- Moving & Confined Landing Platform
- Unusual Airwake Over the Deck of Ship



GUI for DI Flight Profiles

Flight Profile	Test Conditions/Configurations
Test: Quasi-Steady Trim	Atmosphere Model 0: Standard Day
<input type="checkbox"/> Stationkeeping ...	Rotorcraft Position 0: Landing Spot
<input type="checkbox"/> Approach ...	Ambient Pressure Altitude [ft] 96.1883
<input type="checkbox"/> Descent ...	Outside Ambient Temperature [degC] 15
<input type="checkbox"/> Lift off ...	Rotor Rotational Speed [rpm] 257.831
<input type="checkbox"/> Departure ...	Rotorcraft C.G. (Buttline Station) [inch] 0.2004
	Rotorcraft C.G. (Fuselage Station) [inch] 354.096
	Rotorcraft C.G. (x,y,z) in I-frame [ft] 0 0 -96.1883
	Rotorcraft FCS on/off Status [nd] 1
	Rotorcraft Gross Weight [lbf] 19434.8
	Rotorcraft Wheel Height above Deck [ft] 26.83
	Ship C.G. (x,y,z) in I-Frame [ft] 0 0 -64
	Ship Course from North [deg] 0
	Ship Forward Speed [knots] 11.8497
	Ship Landing Spot ID [nd] 1
	Ship Pitch Attitude [deg] 0
	Ship Roll Attitude [deg] 0
	Ship Turbulence Intensity Factor [nd] 1
	Wind Azimuth from North [deg] 0
	Wind Magnitude (horizontal) [knots] 0

Run
Save...
Load...
Close
Help...



DI Stationkeeping



Test Case ID <input type="text"/>		MEMO: Fri Jul 20 12:33:12 PDT 2001	
Case Description <input type="text"/>			
Sweep Option <input type="button" value="0: Ship Speed"/>			
		Min	Max
Ship Forward Speed (knots)	<input type="text" value="10 30 10"/>		
	<input type="button" value="0: Uniform"/>	<input type="checkbox"/> Trim to limit	
		Min	Max
Ship Course from North (deg)	<input type="text" value="-20 20 20"/>		
	<input type="button" value="0: Uniform"/>		
		Min	Max
Ambient Wind Speed (knots)	<input type="text" value="0 30 10"/>		
	<input type="button" value="0: Uniform"/>	<input type="checkbox"/> Trim to limit	
		Min	Max
Ambient Wind Azimuth (deg)	<input type="text" value="-30 30 10"/>		
	<input type="button" value="0: Uniform"/>		
		Min	Max
Wind Over Deck Speed (knots)	<input type="text" value="10 30 10"/>		
	<input type="button" value="0: Uniform"/>	<input type="checkbox"/> Trim to limit	
		Min	Max
Wind Over Deck Azimuth (deg)	<input type="text" value="160 240 20"/>		
	<input type="button" value="0: Uniform"/>		
		Min	Max
<input checked="" type="checkbox"/> Rotorcraft Heading (deg)	<input type="text" value="0 60 30"/>		
	<input type="button" value="0: Uniform"/>		
Ok	Apply	Results ...	Standard Plot
Comparison Plot ...	Close	Help...	

Summary

- Conventional T&E methodologies applied to early aircraft were not designed to share information
- The complexity of modern aircraft combined with limited budgets dictates interoperability and SoS approaches to T&E
- An integrated systems approach to T&E could be used to not only help reduce the cost and cycle time of testing, but would also support the issues of interoperability and systems of systems testing